Impact of Diurnal Cycle Simulation on the TOA Flux Mean State and Interannual Variability in a CMIP5 Model: CanAM4

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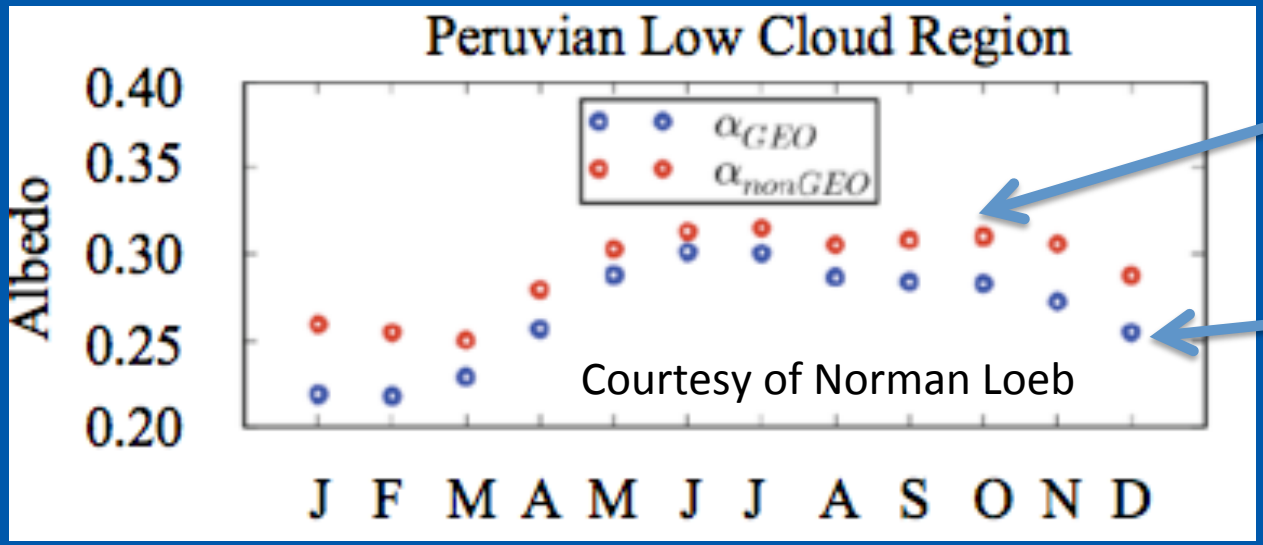
Why Study Diurnal Cycle?

(1) Diurnal cycle influences the time mean energy budget.

- Bergman and Salby (1997) attribute a 1-5 W m^{-2} and 5-20 W m^{-2} to the cloud diurnal cycle in the time mean OLR and RSW.
- Loeb et al. (2009) indicate up to a 30 W m^{-2} biases in MSc and tropical land convective regions in time mean RSW.



Incomplete diurnal cycle

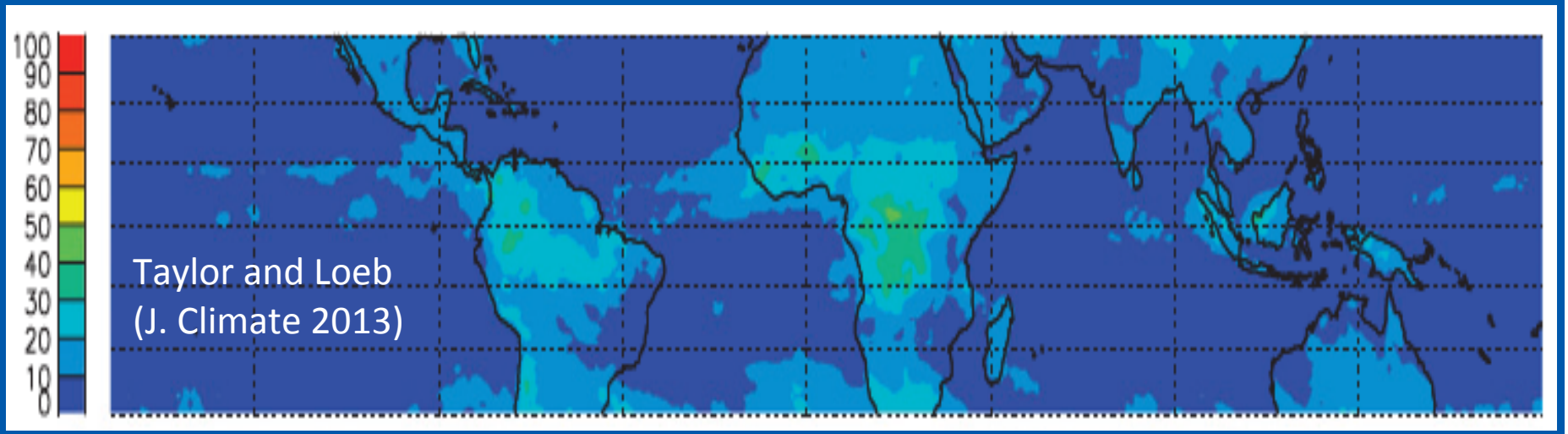
Complete diurnal cycle

Why Study Diurnal Cycle?

(2) Diurnal cycle influences variability of the TOA energy budget terms.

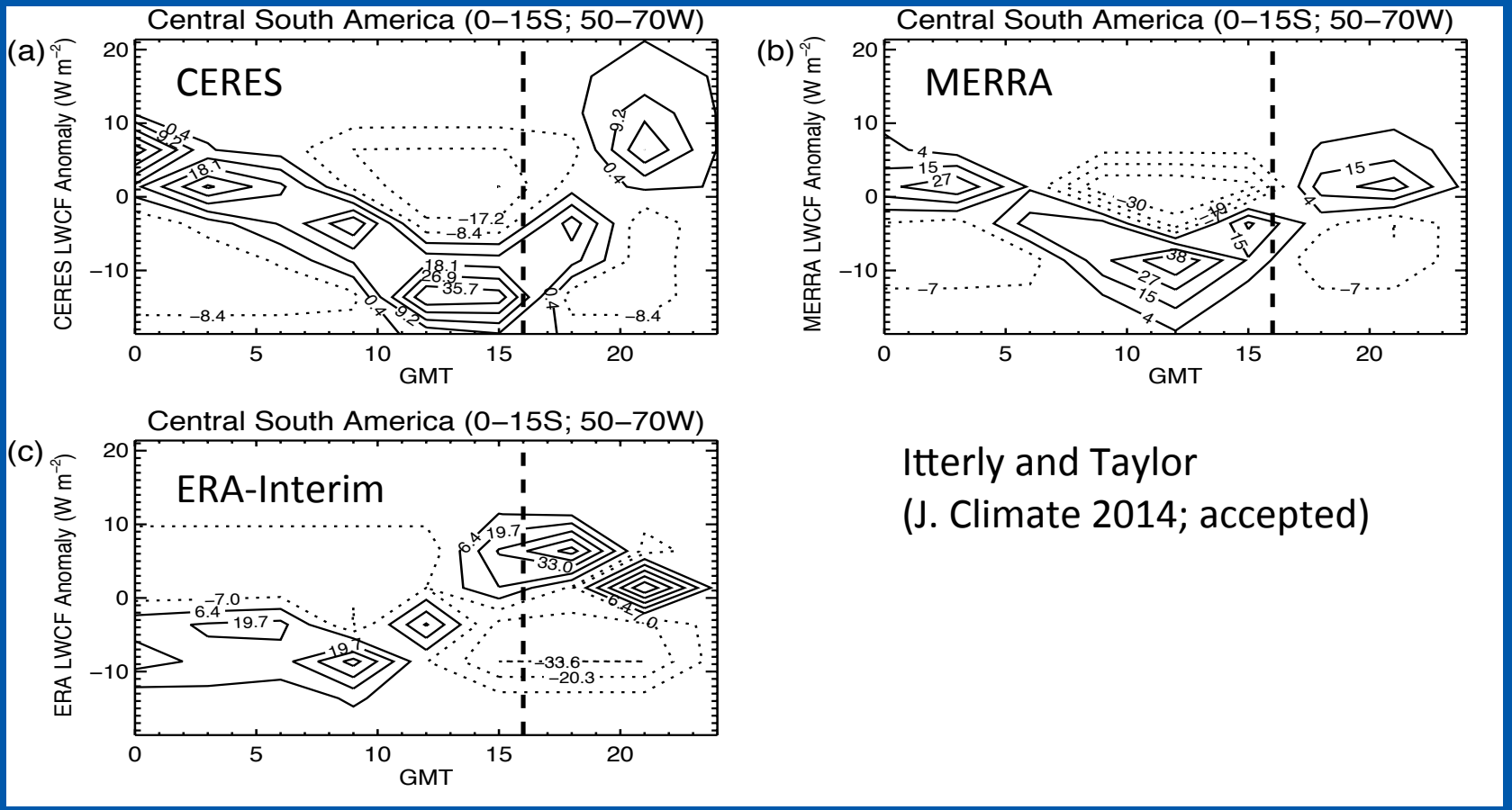
- Taylor and Loeb (J. Climate 2013) and Taylor (J. Atmos. Sci. 2014) indicate that diurnal cycle variability accounts for up to 50% of TOA flux variability at 1°x1° scales.

Units: %



Why Study Diurnal Cycle?

(3) GCMs and NWP models poorly simulate the diurnal cycle.



Itterly and Taylor
(J. Climate 2014; accepted)

Science Questions and Takeaway Messages

1) How large is the diurnal cycle impact on GCM simulated climatological mean state and interannual variability?

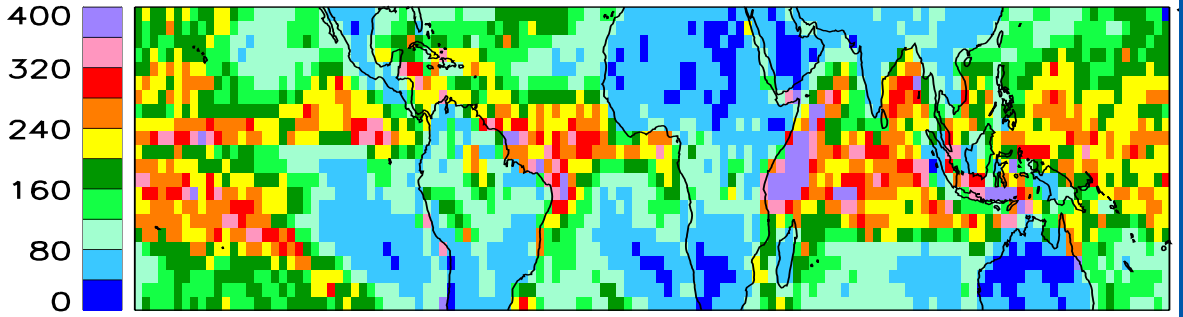
2) How well must a model need simulate the diurnal cycle in order keep mean state and variability errors to acceptable levels?

Data and Model

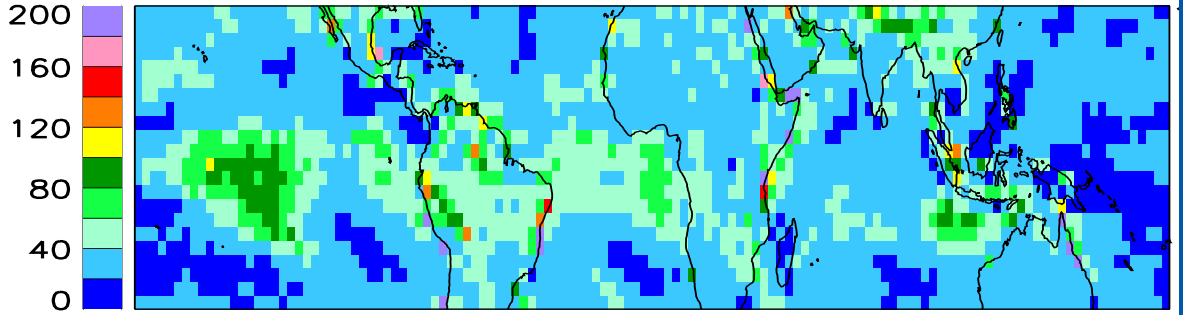
- CERES Ed3 SYN Data (2002-2012; 3-hourly; Doelling et al. 2013)
  (1) calibration of each GEO instrument against MODIS
  (2) a narrowband to broadband radiance conversion
  (3) GEO broadband radiance to irradiance integration
  (4) normalization of GEO derived flux to CERES
- CanAM4 (1-hourly)
  - ~2.8°x2.8° lat/lon horizontal resolution
  - AMIP-style simulation (SST boundary condition)
  - 10 year simulation (2000-2009)

Climatological Diurnal Cycle Evaluation: Longwave

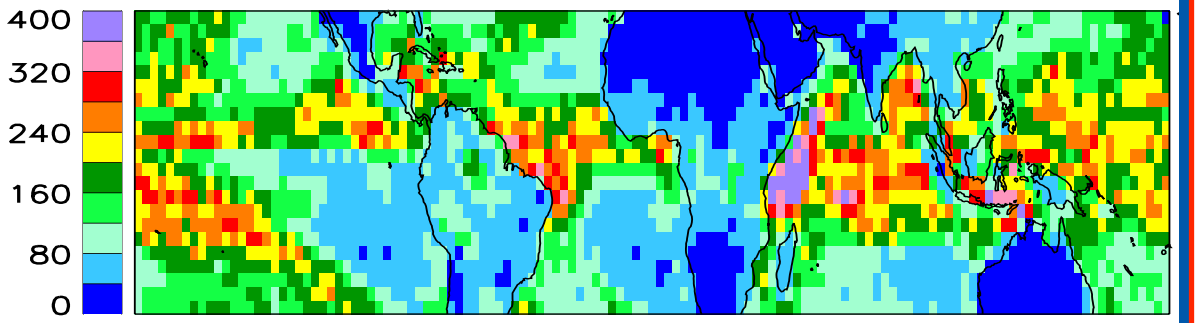
OLR



OLR_{CLR}



LWCF

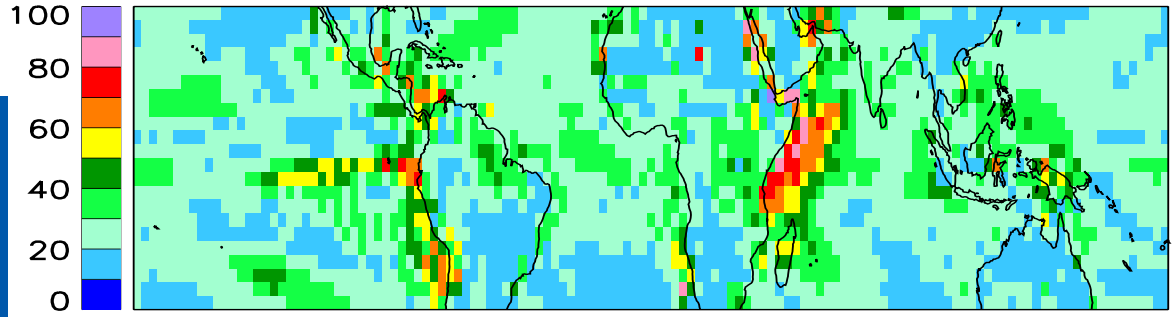


RMS errors are given in percent relative to the standard deviation across the CERES observed OLR diurnal cycle.

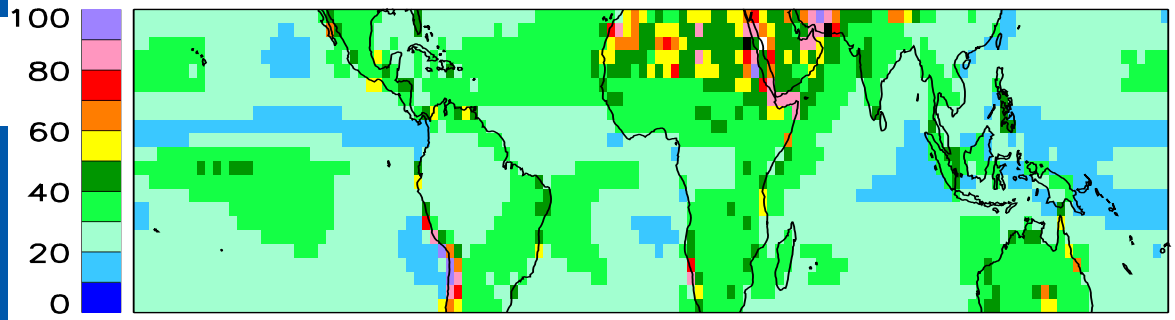
Longwave TOA flux diurnal cycle simulation errors are primarily attributed to errors in the diurnal evolution of clouds.

Model Diurnal Cycle Evaluation: Shortwave

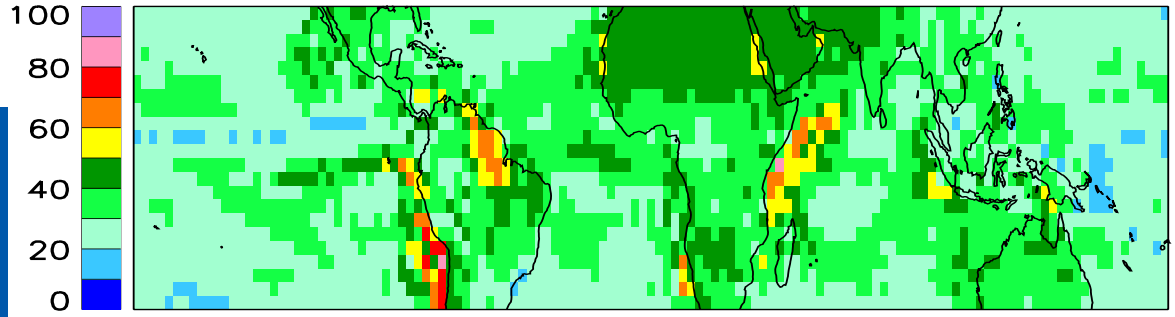
RSW



RSW_{CLR}



SWCF

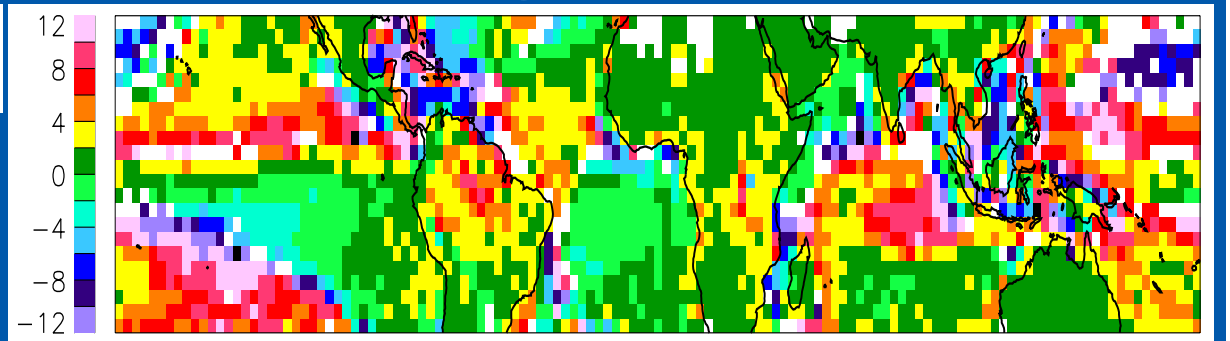


RMS errors are given in percent relative to the standard deviation across the CERES observed RSW diurnal cycle.

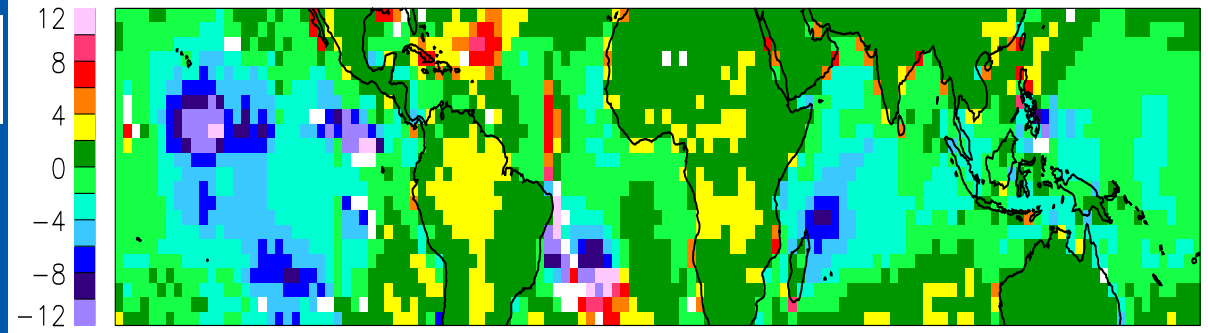
Reflected shortwave TOA flux diurnal cycle simulation errors show significant contributions from both clear and cloudy sky.

Diurnal Cycle Error Attribution: Longwave Phase

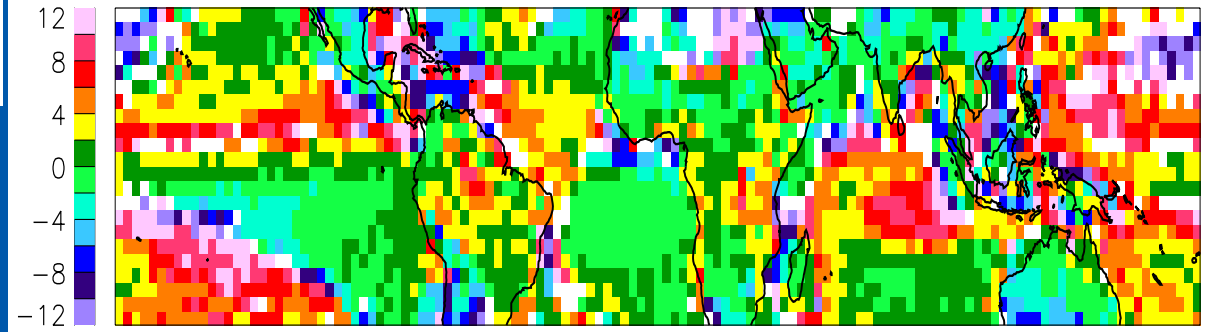
OLR



OLR_{CLR}



LWCF

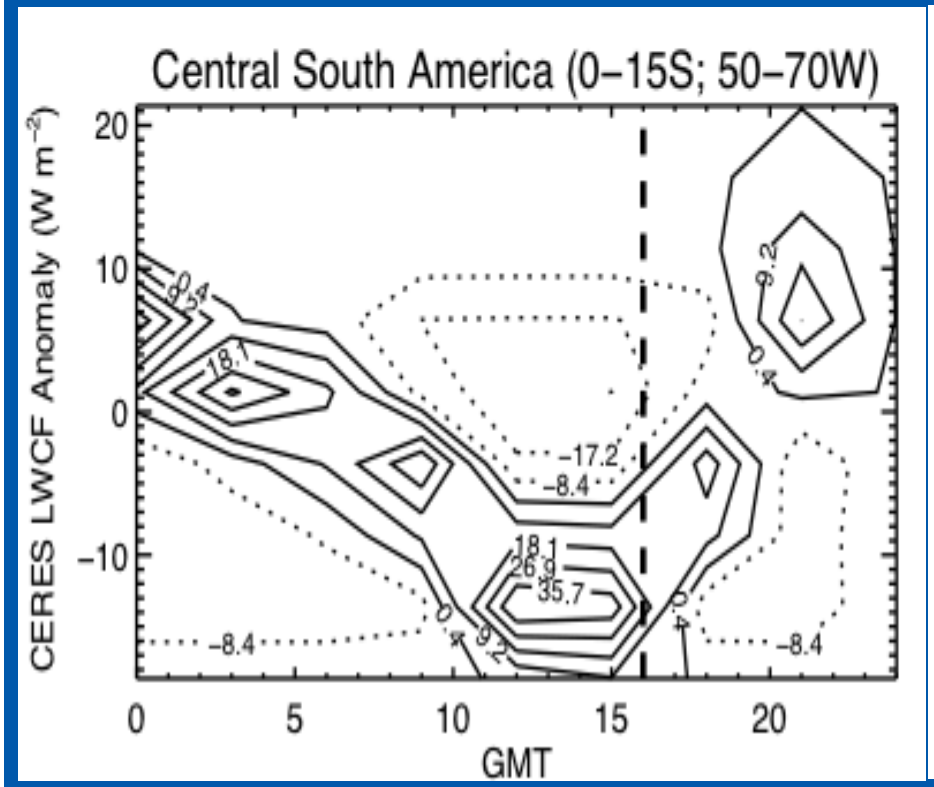


Phase errors are computed (CanAM4 minus CERES.)
-Regions of significant Land-Ocean breeze circulations show the largest phase errors.

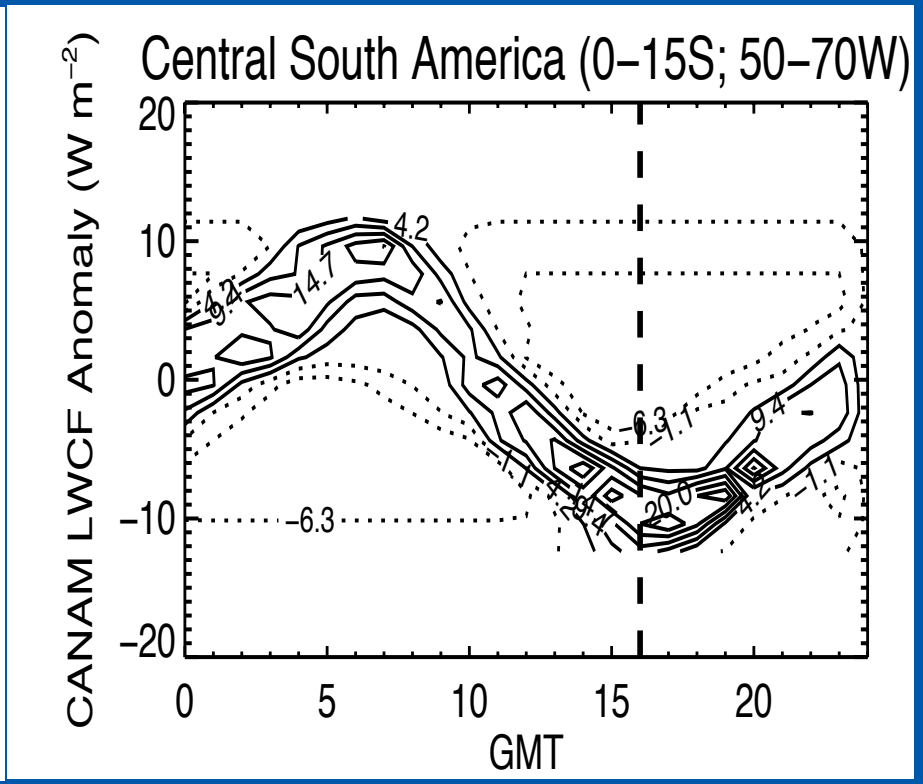
OLR TOA flux diurnal cycle is phase features associated with propagating convection are missing (e.g, Indian Ocean).

Diurnal Cycle Evolution Histogram: Central South America

CERES



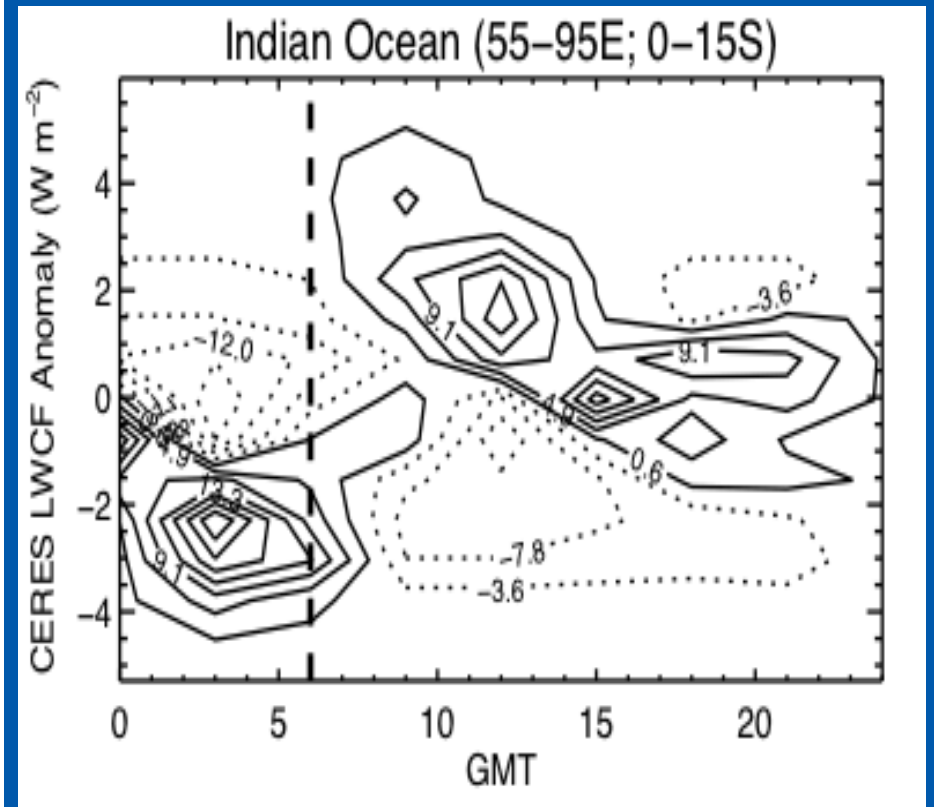
CanAM4



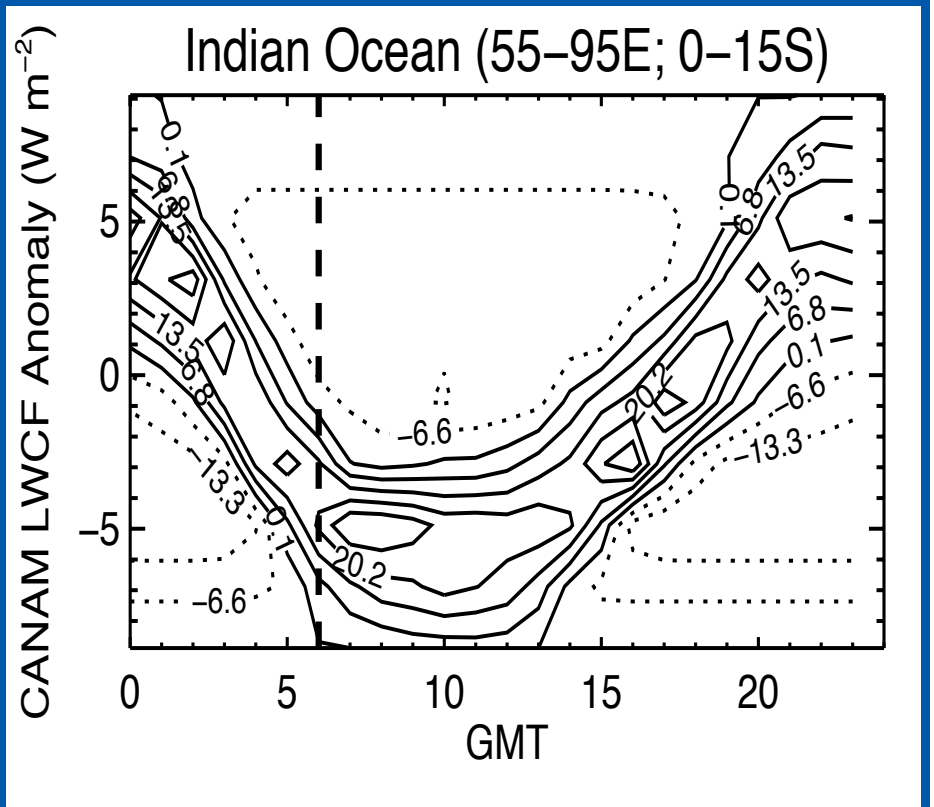
The CanAM4 TOA LWCF diurnal cycle in Central South America has an amplitude that is ~50% too weak with a ~8 hour phase shift.

Diurnal Cycle Evolution Histogram: Indian Ocean

CERES



CanAM4



CanAM4 TOA LWCF diurnal cycle in the Indian Ocean exhibits large differences in the diurnal cycle evolution. The diurnal cycle evolution is similar to MERRA and ERA-Interim reanalyses (Itterly and Taylor 2014, accepted)

Diurnal cycle impact TOA flux mean state and interannual variability?

Diurnal Cycle Contributions to Time Mean TOA flux

Let's consider that the TOA flux is the sum of two components.

$$OLR = OLR_{mon} + OLR_{dc}$$

Total Flux | Diurnally uniform contribution | Diurnal cycle contribution

A similar expression can be written for RSW.

Total flux=> observed or modeled monthly mean

Diurnally uniform=> computed using a radiative transfer model with monthly mean, diurnally uniform inputs (e.g., temperature, atmospheric transmittance, column albedo)

Diurnal cycle=> Total flux minus Diurnally uniform

$$OLR_{mon} = \tau_{eff} \sigma T_s^4$$

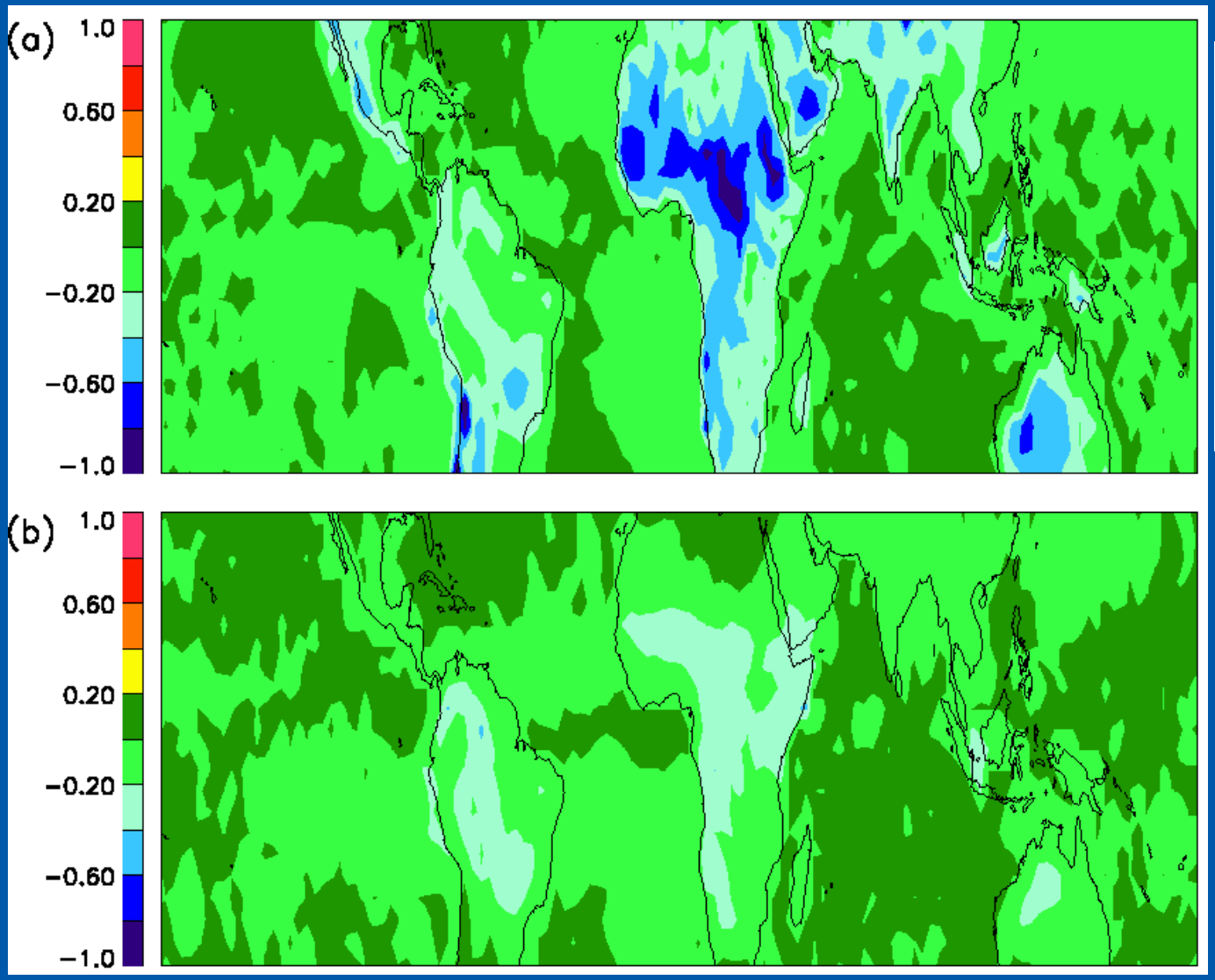
$$RSW_{mon} = \alpha_{mon} S_{ins}$$

Taylor et al. (In prep)

Interpretation

- Longwave Cloud:
  - OLR_dc > 0 occurs when cloud preferentially form at night when T_s is lower.
  - OLR_dc < 0 occurs when cloud preferentially form during the day when T_s is higher.
- Shortwave Cloud:
  - RSW_dc > 0 occurs when cloud preferentially form in the afternoon when Solar insolation is high.
  - RSW_dc < 0 occurs when cloud preferentially form in the morning or evening when Solar insolation is low.

Mean State: LWCF_DC Contributions

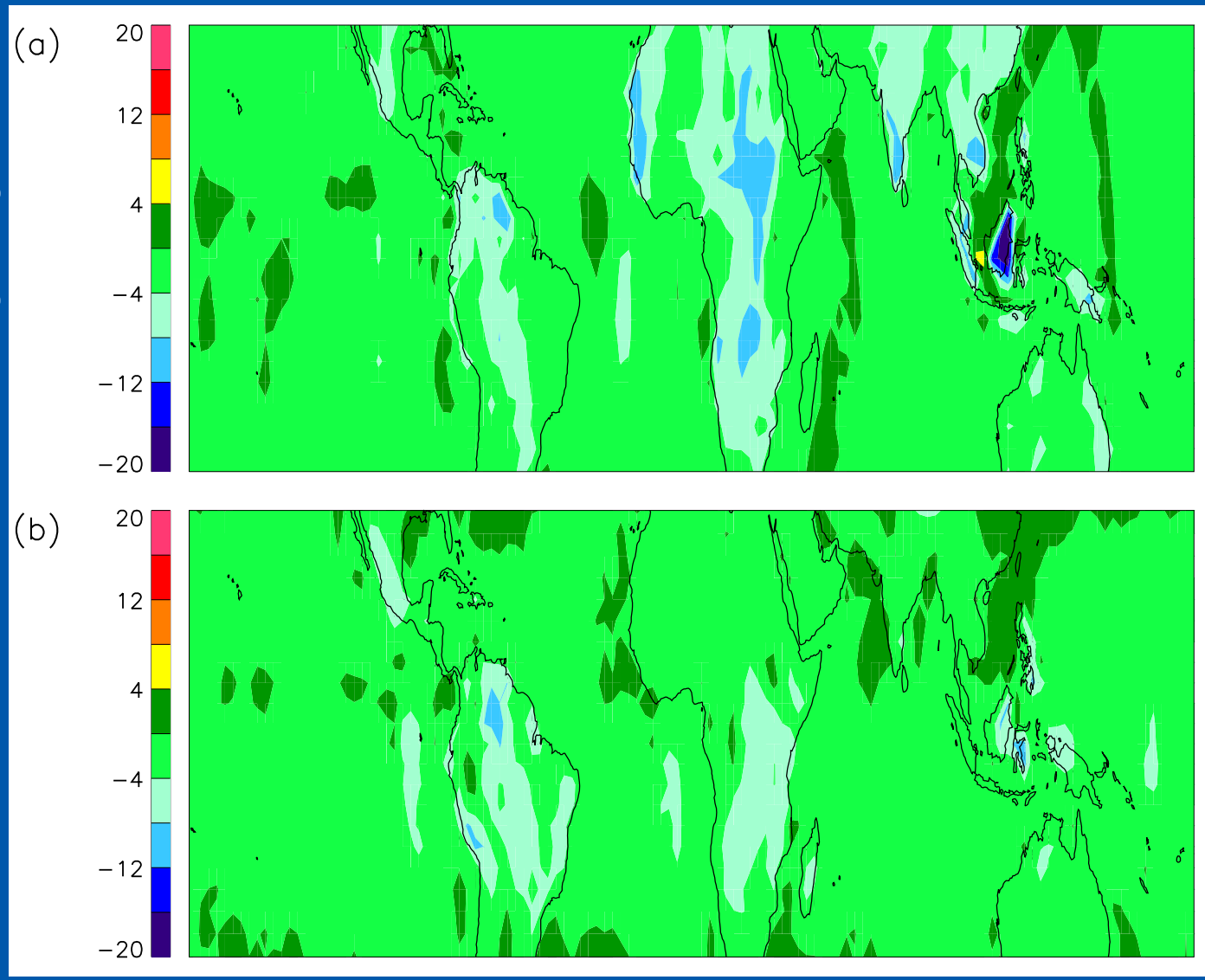


Shown are the contributions of the LW cloud diurnal cycle to the (a) CERES and (b) CanAM4 OLR mean state.

CanAM4 LW cloud diurnal cycle contributions to mean state OLR are the same sign as CERES but are **too weak**.

Taylor et al. (2014; in prep)

Mean State: SWCF_DC Contributions



Shown are the contributions of the LW cloud diurnal cycle to the (a) CERES and (b) CanAM4 OLR mean state.

CanAM4 SW cloud diurnal cycle contributions to mean state RSW are the same sign as CERES but are **too weak**.

Taylor et al. (2014; in prep)

Diurnal Cycle Contributions to TOA flux Variability

First, the OLR time series is decomposed into three components.

$$\mathrm{OLR}(y,m,h) = \mathrm{OLR}_{\mathrm{clim}}(m,h) + \delta\mathrm{OLR}_{\mathrm{shift}}(y,m) + \delta\mathrm{OLR}_{\mathrm{dc}}(y,m,h);$$

The components are

(1) the monthly, climatological diurnal cycle,
(2) the monthly anomaly, and
(3) the deviation of the diurnal cycle from climatology

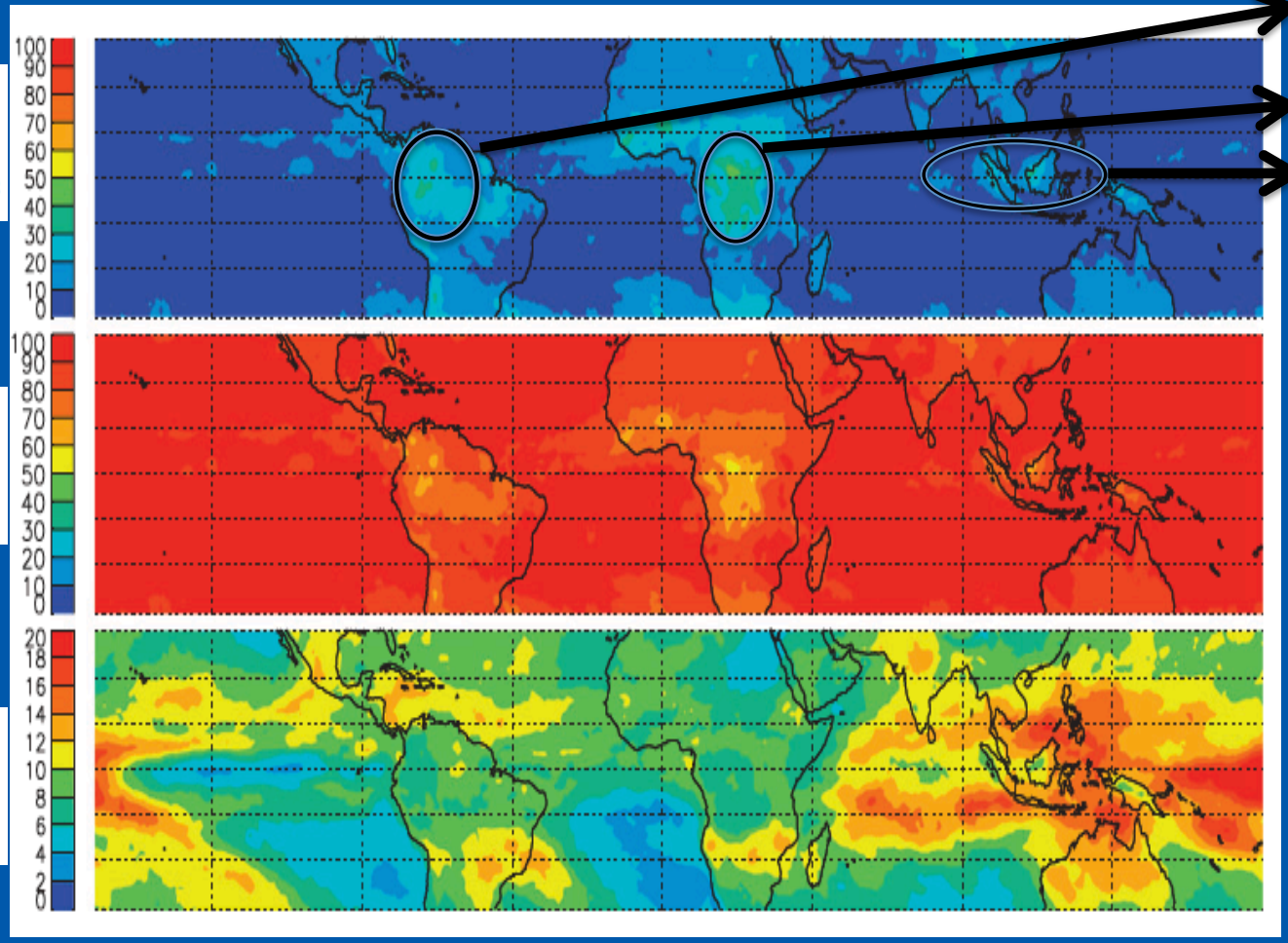
Expressing the OLR time series in this manner allows the variance to be decomposed into monthly anomaly and diurnal cycle deviation contributions.

Total variance | Monthly variance | Diurnal variance

$$\sigma^2_{\mathrm{OLR}'} = \sigma^2_{\mathrm{OLR}_{\mathrm{shift}}} + \sigma^2_{\mathrm{OLR}_{\mathrm{dc}}}$$

Taylor and Loeb (J. Climate 2013)

Diurnal Cycle Contributions to TOA flux Variability

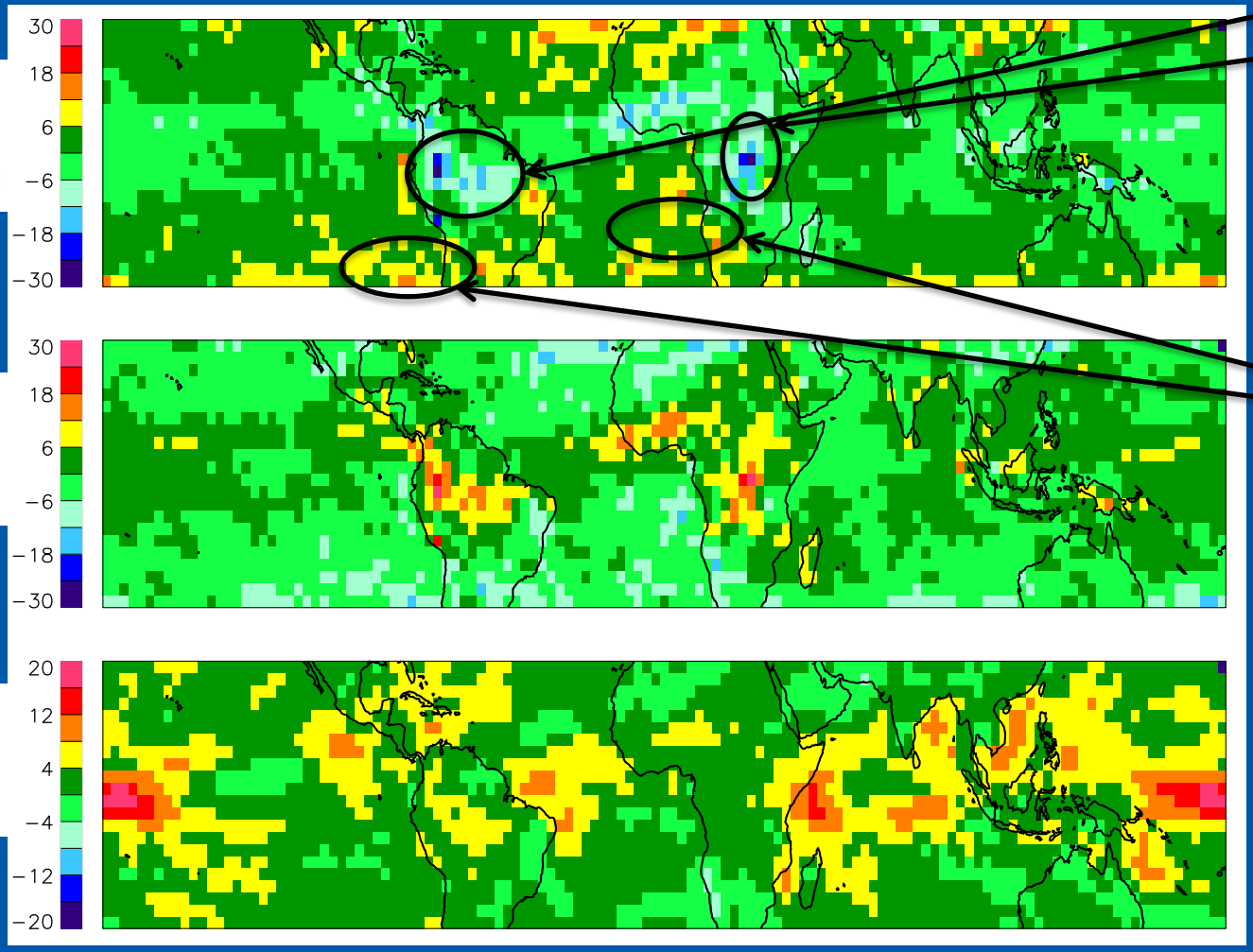


Variance contributions from the diurnal cycle exceed 40% in these regions.

Largest contributions of the diurnal cycle to TOA flux variability--reaching 50%--occurs in land convective regions.

Taylor and Loeb (J. Climate 2013)

Variance decomposition: CanAM4 minus CERES



OLR_dc variance contributions too small

OLR_dc variance contributions too large

OLR diurnal cycle contributions to TOA flux variability are too small in land convective regions and too large in MSc regions.

Science Questions and Takeaway Messages

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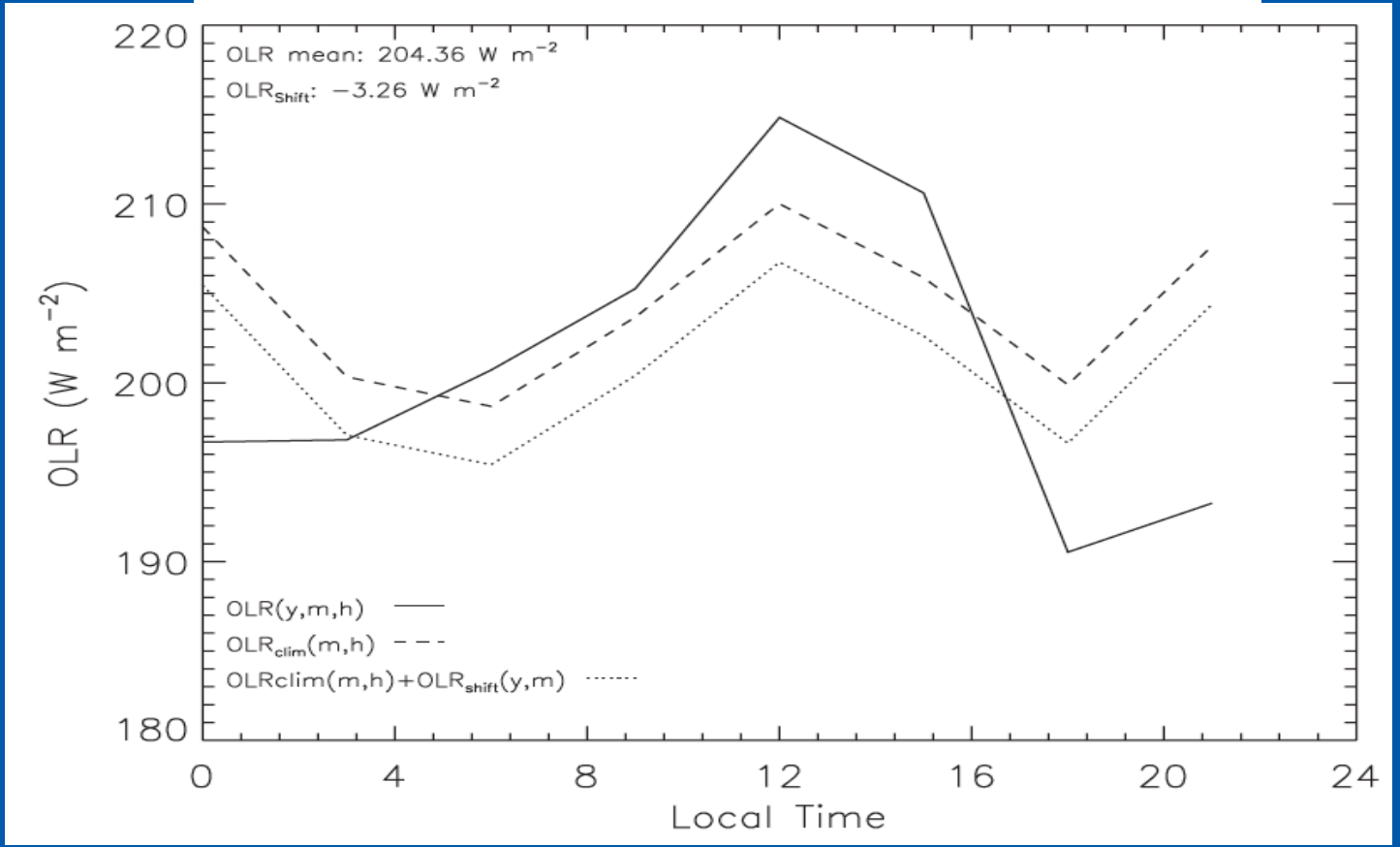
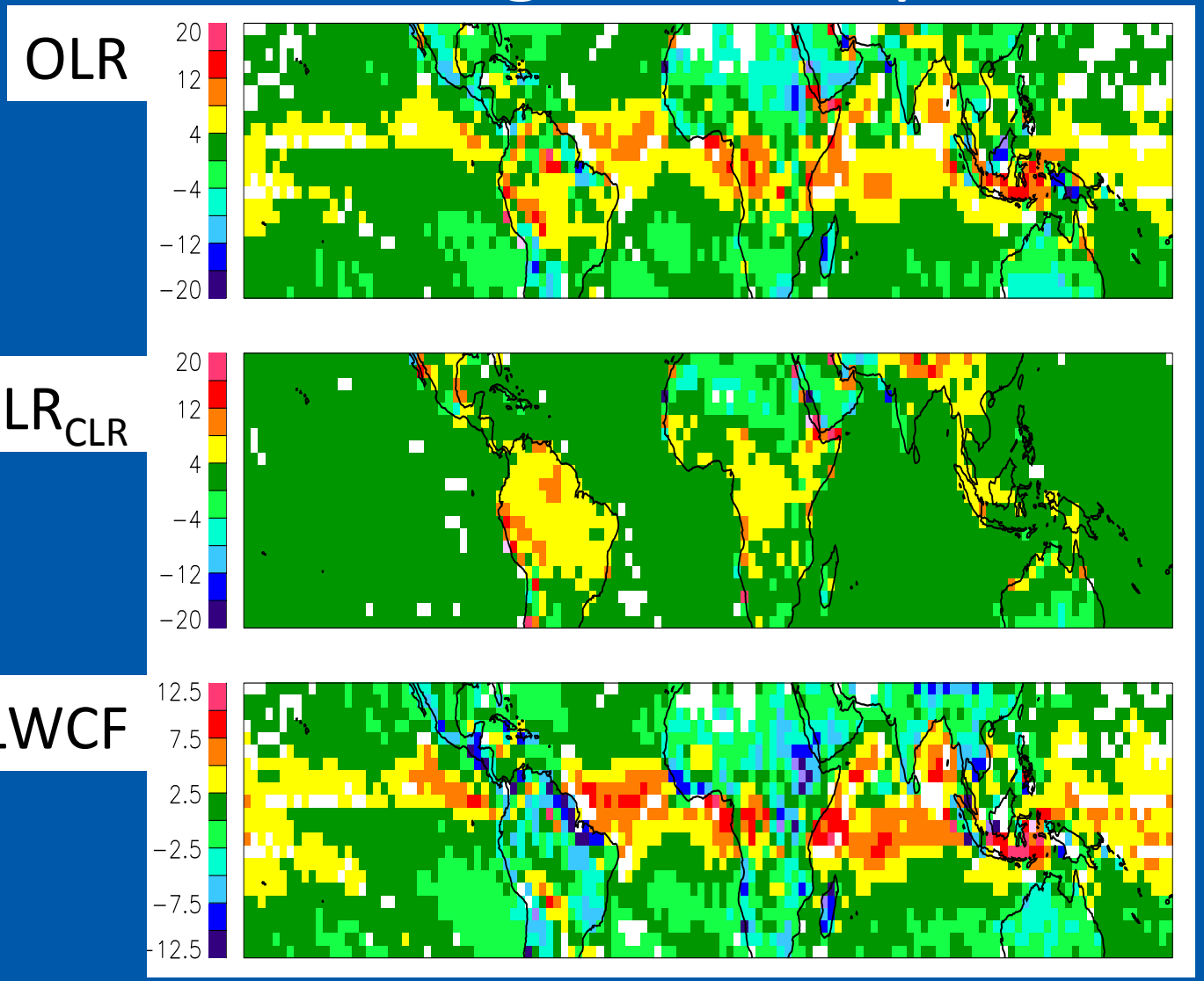
Diurnal Cycle Contributions to TOA flux Variability

$$\mathrm{OLR}(y,m,h) = \mathrm{OLR}_{\mathrm{clim}}(m,h) + \delta\mathrm{OLR}_{\mathrm{shift}}(y,m) + \delta\mathrm{OLR}_{\mathrm{dc}}(y,m,h);$$



Diurnal Cycle Error Attribution: Longwave Amplitude



Amplitude errors are computed as CanAM4 minus CERES.
-Land convective regions show the largest amplitude errors.

OLR TOA flux diurnal cycle amplitude is too strong in land convective and too weak in land non-convective regions.

Diurnal Cycle Error Attribution: Shortwave Amplitude